User-Centered Design and Evaluation of an Ambient Event Detector Based on a Balanced Scorecard Approach

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***Abstract*—The user-centered design of an e-health system is a complex endeavor: the conflicting interests of multiple user perspectives have to be balanced throughout the design process. Moreover, a common understanding of the interplay between technical, psychological and business aspects has to be developed among multi-disciplinary project partners. In this paper, we describe how the European ambient assisted living project *fearless* deals with these challenges of a user-centered design process based on a balanced scorecard approach.**

***Keywords*-Ambient assisted living, ambient event detector, user-centered design, balanced scorecard.**

I. Introduction

The European ambient assisted living (AAL) project *fearless*[1] ("Fear Elimination As Resolution of Elderly's Substantial Sorrows") is dedicated to fall detection and inactivity monitoring in the homes of solitarily living elderly. For this purpose an autonomously operating ambient event detector is being developed in a user-centered design process [1]: technical specification of the first prototypes is based on two multi-cultural user requirements surveys targeting elderly people (*N*=259), their relatives and trusted persons (*N*=215) as well as 22 representatives of care taker organizations. The prototypes of the ambient event detector have been tested extensively under laboratory conditions (e.g., [2]–[6]) yielding promising results. At present these results are being verified in two longitudinal field pilot studies including 45 elderly test users and care taker organizations from Austria, Germany, Italy, and Spain.

The *fearless* consortium comprises ten multi-disciplinary partners from Austria, Germany, Italy, and Spain. While technical partners are working on fall detection algorithms and setting up a telematics platform for alarm handling, two care taker organizations are responsible for the recruitment of elderly test users. Tools for the analysis of user needs and a continuous user-centered evaluation process are designed and deployed by cognitive psychologists from the department of General Psychology and Methodology at the University of Bamberg. Medical experts are counseling the project consortium in terms of ethical issues. Last but not least, business experts are responsible for bringing the *fearless* technology to the market. Market research is conducted and a business model is designed taking different national health care systems into consideration.

User-centered design is essential for the development of assistive technologies. Yet, designing an e-health system becomes a highly complex endeavor as soon as multiple stakeholders are involved: first and foremost, the conflicting interests of complementary user perspectives have to be balanced throughout the design process. Moreover, a common understanding of the interplay between technical, psychological and business aspects has to be developed among multi-disciplinary project partners. In the following sections of this paper, we describe how the AAL-project *fearless* deals with these challenges based on a balanced scorecard (BSC) approach: Section II is dedicated to the current state of technology used in the *fearless* project. In Section III the concept of the balanced scorecard is introduced. An overview of the different stages of user integration within the *fearless* project is given in Section IV. Subsequently, the results of a primary and a secondary user requirements survey are presented in Section V and Section VI. Section VII deals with the Technological Impact Assessment Model, which integrates the results of these two user requirements surveys. In Section VIII, the specific challenges and trade-offs are discussed, which have aroused in the course of a user-centered design process including multiple user perspectives. Finally, in Section IX conclusions are drawn and an outlook is given.

II. Current State of Technology

The structure of the *fearless* system is depicted in Figure 1, showing all relevant interfaces and involved end users. The proposed e-health system consists of sensor units (Xtion Pro™ + small PC for data processing) installed at the elderly's house or flat. The system is adaptable, hence standardized interfaces to third parties are provided (e.g., burglar alarm system, gas detector). Unusual events (e.g.,

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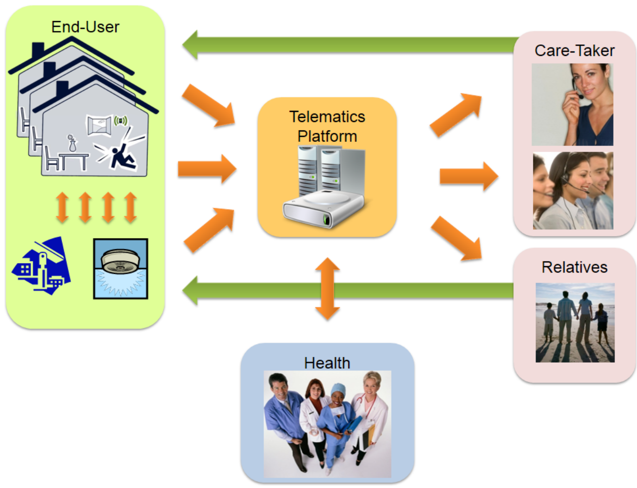

Figure 1. Organizational workflow

falls) are detected automatically and alarms are sent to the telematics platform. This platform enables relatives and care takers to handle alarms. Furthermore, the telematics platform offers interfaces to different standardized electronic health record systems (e.g., ELGA in Austria) to include health professionals.

The *fearless* system works autonomously and raises alarms wihtout any user intervention, since it is important to reduce the cognitive load on the user, especially when dealing with dementia [7]. The use of computer vision is feasible, since it can overcome the limitations of other sensor types [8] and no devices need to be worn. Zweng et al. [6] show that the accuracy of their fall detection approach is higher compared to 2D cameras when using a calibrated camera setup and a 3D reconstruction of a person. Hence, we propose to use a Kinect™ / Xtion pro™, since 3D information is available for distances up to ten meters without the need for a calibrated camera setup. However, the SDK is optimized for a range from 0.8 to 3.5 meters and thus not all features provided by the SDK can be used for higher distances (e.g., NITE). Moreover, the scene can be analyzed in more detail (e.g., estimation of the ground plane) in comparison to standard cameras. Due to the sensor range of ten meters, one sensor is able to cover one room. The total number of sensors per flat highly depends on the layout of the rooms and user preferences. Users with a high risk of falling may choose to equip their flat with many sensors, whereas user with a lower risk of falling may choose to place sensors in rooms with a higher probability of falling (i.e., living room) only. The *fearless* system also works with multiple persons and detects falls not only directly, but also includes additional heuristics to detect “unusual behaviour” indicating a fall (e.g., person has disappeared behind a sofa).

Nevertheless, the use of computer vision raises privacy issues. Due to this fact, the Kinect™ respectively the Xtion Pro™ sensor is used, since depth data can be used to detect falls accurately (e.g., [3], [4]). Using depth data respects the privacy of elderly, since neither the person nor the surrounding can be identified from depth images. A depth image only visualizes the position and the distance to the sensor. Figure 2 (left) shows an example of a depth image illustrating a person, tables and a mat lying on the floor. This visualization illustrates the distances of subjects and objects to the sensor. The brighter the color in the depth image, the further away the person or object is. On the other hand, the darker the object is, the closer to the sensor it is. Furthermore, black indicates that there is no data available (e.g., due to sunlight or reflections). In contrast, the corresponding RGB image is shown in Figure 2 (right), representing the same scene.

The workflow of our approach is depicted in Figure 3: starting with a depth image, the skeleton and ground plane data is extracted by the use of OpenNI [9]. The skeleton joints of the shoulder, spine and the center of the hip are extracted and analyzed using fuzzy logic. Based on the results of the fuzzy logic, a decision is made if the person is in an upright position or lying on the floor. Since only the skeleton joints are used, the privacy of the elderly is respected due to the use of an anonymous and abstract visualization only using lines and dots. An example of this visualization is shown in Figure 4: the dots are representing the upper part of the body, whereas the line represents the major body orientation and the ground floor. In case of an alarm, the alarm including this abstract visualization is sent to the telematics platform, depicted in Figure 3. Moreover, the alarm is stored and forwarded to the appropriate care taker organization or relative by using this platform.

III. Balanced Scorecard (BSC)

The user-centered design of an e-health system is a complex endeavor: multiple user perspectives and their conflicting interests have to be balanced throughout the design process. Moreover, a common understanding of the interplay between technical, psychological and business aspects has to be created among the multi-disciplinary project partners. A performance management system can help reduce complexity by drawing our attention to those aspects critical

Figure 2. Depth image (left) and corresponding RGB image (right)

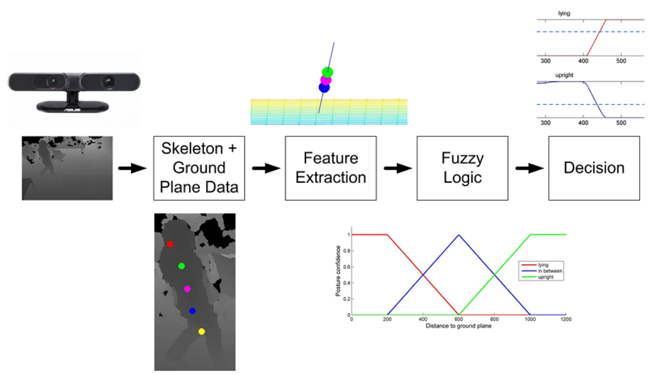

Figure 3. Technical workflow of the *fearless* system

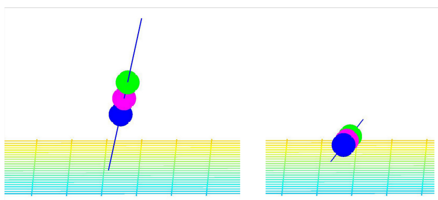

Figure 4. Illustrations used for verification a person standing upright (left) vs. a person lying on the floor (right)

for success. In 1992, Kaplan and Norton have introduced a new type of performance measurement system to the field of business administration [10]: the Balanced Scorecard (BSC). Based on an explicit "theory of business" [11, p. 110] a BSC combines measures and indicators that reflect different stakeholder perspectives and their conflicting interests. Thus, a BSC enables executives and project managers to "see whether they have improved in an area at the expense of another" [10, p. 1]. Basically, a BSC has to give answers to the following questions:

- Who are the relevant stakeholders?
- What are the needs and expectations of these stakeholders?
- How are stakeholder perspectives interrelated?
- What are appropriate measures and indicators for tracking these needs and expectations?
- Which aspects have to be balanced in the user-centered design process?

In the following sections, we will answer these questions for the *fearless* project. The resulting *fearless* scorecard will be used for project evaluation in the user-centered design process of an e-health system.

IV. Concept and Phases of User Involvement

Figure 5 illustrates the integration of the end users within the *fearless* project: at the beginning of the project, two multi-cultural user requirements surveys were conducted in order to assess the needs (e.g., fears) and expectations of

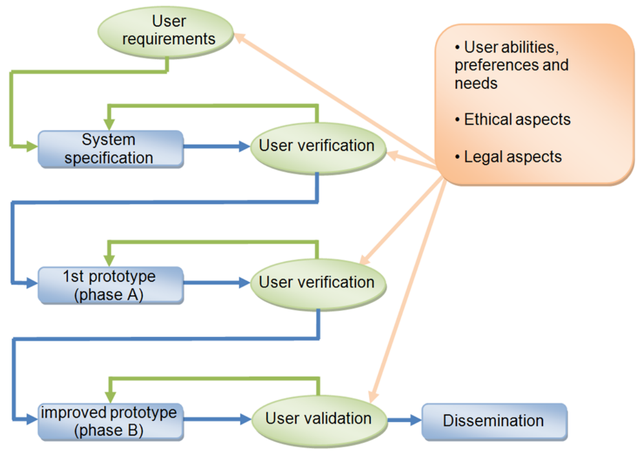

Figure 5. User involvement in the *fearless* project

primary and secondary end users. According to the user requirements, an initially defined system specifications are evaluated by test users and redefined on a regular basis in the course of two field pilot studies. Field pilots in combination with semi-structured interviews are conducted to ensure that the *fearless* system is tailored to the end user's needs. Since end users provide regular feedback, the technical specification of the *fearless* system is adapted throughout the project.

Who are the stakeholders of the projected e-health system? In the *fearless* project the design process is centered on two groups of users: Older adults (aged 60+) who wish to use the e-health system in their private home. In the following, this group of users is referred to either as primary users or as clients. Together with their closest relatives and other trusted persons these potential users are involved during user analysis and field pilots. The second user perspective is represented by members of care taker organizations that offer services related to the projected e-health system. Just like the primary users these people will be interacting with the *fearless* system on a daily basis: as technicians they will be engaged in hardware installation and maintenance, as members of the call-center staff they will interact with the telematics platform handling the alarms. In the following this group of users is referred to as secondary users. Secondary users are also involved throughout the design process: from user requirements analysis to field pilot evaluation.

During the field pilots the *fearless* system is installed in elderly's flats in Austria, Germany, Italy, and Spain. The field pilots consist of two different phases: during phase one, the first prototype of the fall detection system is installed in 16 flats (four flats in each country) to obtain first results of the system. Due to these results the prototype is enhanced before phase two with more than 40 installations will be conducted. The aim of the field pilots is not only to test the fall detection system itself, but also to assess technological and psychological aspects (e.g., housing-related control beliefs) as well as integrating care taker organizations and relatives throughout the project. Furthermore, also ethical commissions are involved during the field pilots to verify the feasibility of the *fearless* system from a legal and an ethical point of view.

The project benefits from the different interdisciplinary perspectives, from which the results of the field pilots are analyzed. From a technical point of view, the fall detection algorithm [4] is tested under real settings and is adapted to the end users' needs while overcoming the lack of realism when performing falls in the laboratory. Furthermore, the overall system including its interfaces as well as the feasibility of the system setup are evaluated. From an organizational point of view, end user organizations are able to integrate the system into their workflow and provide feedback to adapt the system to their needs. Elderly are involved to provide essential feedback to the technical partners. Additionally, we expect to reduce their fears by providing safety while using our system. Since the field pilots are conducted with medical and psychological support, changes and benefits for elderly can be determined and these assumptions can be verified.

In summary, the following user groups are involved in the *fearless* project:

- **Elderly and relatives** are involved during the user requirements analysis and during the field pilots. Elderly install the system in their flats during the field pilots, whereas their relatives can receive the alarms if unusual events are detected.
- **Care takers** are involved during the user requirements analysis and are fully integrated during the field pilots. Hence, the care takers' call centers are integrated and alarms are forwarded to the appropriate call center. This allows for an evaluation of the overall workflow in case of an alarm.

V. Primary User Requirements Survey

What are the needs and expectations of prospective users? Of course user involvement starts with a thorough analysis of primary and secondary user needs. Thus, two multi-cultural user requirement surveys were conducted prior to technical specification of the first *fearless* prototypes [12]. The first survey addressed the needs and expectations of older adults (aged 60+), their closest relatives and other trusted persons. Based on the results of this survey we sought for answers to the following questions: What do elderly people actually fear? Which functions of an e-health system would be desirable in order to resolve these fears? Besides, two more specific questions were targeted: Where do falls occur? How much are users willing to spend on an ambient event detector and the services related to it? 259 potential primary users from Austria, Germany, Italy, and Spain (Catalonia) took part in this survey. The participants were aged between 59 and 101 years ($M = 73.6; SD = 8.3; Mdn = 73.0$). Additionally, we surveyed 215 relatives and trusted persons of potential primary users. All participants either filled in a questionnaire or participated in a standardized face-to-face interview. Primary users answered questions about resources and deficits of their private home, previous falls and fears related to a broad variety of critical incidents (e.g., falls, fire, housebreaking, etc.). Besides, they were asked to specify preferred functions and an appropriate pricing for a custom-tailored ambient event detector. Relatives and trusted persons answered these questions from a third-person perspective [12]. Across all cultures suffering a stroke in the absence of others was perceived as the most troubling event by primary users and relatives alike followed by events related to falling (Figure 6). Elderly people from Austria, Italy and Spain were particularly worried about housebreaking whereas solitarily living elderly from Austria and Germany reported fear of social isolation. The most preferred functions for a new ambient event detector were fall and fire detection followed by a burglar alarm function, gas detection and inactivity monitoring (Figure 7). In terms of pricing primary users and their relatives stated that hardware must not cost more than 200 Euros whereas monthly expenses for services related to the *fearless* system should be less than 50 Euros. From the survey data a set of seven requirements was derived: maintenance of social networks, stabilization of internal housing-related control beliefs, enhancement of falls efficacy and mobility, reliable fall and fire detection, adaptability (system should allow for additional functions, e.g., burglar alarm), and last but not least affordability [12].

VI. Secondary User Requirements Survey

A second requirement survey was conducted in order to capture the needs and expectations of professional care takers [12]. On the basis of this survey data we sought for answers to the following questions: Which functions should an innovative e-health system provide in order to meet the needs and expectations of care taker organizations? Which aspects of a new e-health system are critical for success? 22 participants from Austria ($n=3$), Germany ($n=7$), Italy ($n=10$), and Spain ($n=2$) either filled in a questionnaire or participated in a standardized face-to-face interview. They answered questions about their previous experience with current tele-care devices (e.g., panic button) and their expectations towards innovative e-health technology. Furthermore, they were asked to specify preferred functions and an appropriate pricing for an ambient event detector. In spite of its size the expert sample reflects a broad variety of different organizations and professions from the field of healthcare: members of research organizations, SMEs and large care taker organizations were included. The participants were employed either by profit ($n=8$) or non-profit ($n=14$) organizations [12]. Across different healthcare systems and individual areas of expertise four functions were favored by

Critical Incidents	Austria		Spain		Germany		Italy	
	Elderly	Relatives	Elderly	Relatives	Elderly	Relatives	Elderly	Relatives
Suffering a stroke	X	XX	X	XX	X	X	X	X
Burglars break into the house	X		XX	XX	(x)		(x)	
Slipping in the bathroom		(x)	X	XX	(x)	(x)	(x)	
Falling down the stairs			X	XX	(x)	(x)	(x)	
Fire caused by a hot plate			X	XX				X
Fire caused by electrical defect			X	XX				X
Fire caused by a hot iron			(x)	XX				X
Fire caused by lightning strike			X	X				X
Burst of a water main			X	X				
Gas leakage			X	X				

Each critical incident was rated on a 5-stepped rating scale from 1= *does not worry me* to 5= *worries me very much*

(x) = average rating between 2.5 and 3.0

X = average rating between 3.0 and 4.0

XX = average rating above 4.0

Figure 6. Prevalent fears of elderly people and their relatives across the four cultures

professionals: fall and fire detection, inactivity monitoring, and gas detection (Figure 7). Requirements for an innovative ambient event detector could be identified as follows: data protection, usability, accreditation, interoperability, and reasonable costs for hardware and services. Due to a severe shortage of trained care personnel in their countries, experts from Germany put special emphasis on low staff intensity in terms of installation, maintenance and handling of the e-health system [12].

VII. Technological Impact Assessment Model

How are the two user perspectives interrelated? What are appropriate measures for a user-centered outcome evaluation? In order to answer these two main research questions the *Technological Impact Assessment Model (TIAMo)* has been developed by psychologists from the University of Bamberg [12]. One of the basic assumptions of the TIAMo is that user perspectives can be arranged hierarchically according to the value added chain. First of all, an innovative e-health system has to meet the needs and expectations of service providers. Otherwise corresponding services will not be available for primary users in the first place - of course this does not apply to the cases in which the *fearless* system is used independently from a care taker organization (e.g., by primary users and their relatives). Thus, our model suggests that the secondary user perspective forms the basis of the TIAMo (Figure 8). In the following sections, we will take a closer look at the requirements for each user perspective. The interdependencies between single requirements are described by arrows. The arrows point to the necessary conditions for each requirement. For example, whether the e-health system is affordable or not depends among other factors on the costs for services, which again depend on staff intensity.

A. Measures and Criteria for the Secondary User Perspective

In accordance with the results of the corresponding requirement survey the secondary user perspective is represented by a set of eight variables: (1) privacy and data protection, (2) usability, (3) reliability of fall and fire detection, (4) staff intensity, (5) accreditation, (6) costs for hardware and (7) services as well as (8) interoperability, illustrated in Figure 9.

Privacy and data protection. Of course compliance with national and European data protection laws is a sine qua non for an e-health system. What are appropriate criteria for evaluating privacy and data protection? Within the European Union Germanys data privacy act is the most restrictive. Thus, it will be applied to the *fearless* system as a standard for the handling of personal data.

Usability. Besides privacy and data protection usability is the most essential requirement. An e-health system has to be reliable and easy to handle. Important pieces of information (e.g., the current status of the client) have to be displayed

	Austria		Spain (Catalonia)		Germany		Italy		Healthcare professionals
	Elderly	Relatives	Elderly	Relatives	Elderly	Relatives	Elderly	Relatives	
Fall detection	X	X	X	X	(x)	(x)	X	XX	XX
Fire detection	X		XX	X	X	(x)		X	X
Burglar alarm			XX	X	(x)		X	X	
Gas detection			X	X			X	X	X
Inactivity monitoring			X	X	(x)	(x)			X
Flooding			X	X					
Monitoring of daily routines			X	X					
Light triggered by motion	X				(x)				

(x) = functions appreciated by at least 30% (only applied to German samples)

X = functions appreciated by at least 50%

XX = functions appreciated by at least 70%

Figure 7. Preferred functions across user perspectives and different cultures

comprehensibly. Usability aspects are closely related to staff intensity: only if the *fearless* system functions reliably it may relieve rescue staff. Only if it is easy to operate it will not require intensive training. What are appropriate measures for usability evaluation? A log-file template has been created to document any technical problem that occurs during pilot implementation. It is filled in by the professional care taker in charge and forwarded to the project partners responsible for technical support and outcome evaluation. In addition, a self-devised "Expert Checklist" was developed by psychologists from the University of Bamberg is handed out to the professional care takers after a single test installation has been completed. They are asked to rate the overall usability of the *fearless* system on a five point rating scale (Item E09: "Compared with the tele-care devices we have been using so far usability and handling of the *fearless* system are very good" ; 1 = "I strongly disagree" to 5 = "I strongly agree"). Apart from the "Expert log-file" and the "Expert Checklist" the usability of the telematics platform is also evaluated in a separate usability study, which comprises a participatory observation and a subsequent interview. The participatory observation takes place in a laboratory at the University of Bamberg. Participants are asked to navigate the telematics platform and to respond to a series of test alarms that are generated by the conductor of the study. Afterwards the participants are interviewed about their user experience and point out areas of improvement.

Reliability. A crucial aspect of usability of the *fearless* system is its reliability in terms of fall detection. To measure the reliability of the system, the number of false alarms / false positives (FP) is evaluated. This number can also be compared to similar alarm systems (e.g., panic button) since a button push without the actual need for help can be considered as false positive. How do we assess reliability of fall detection? The applied fall detection approach is introduced and evaluated under laboratory conditions by Planinc and Kampel [4], [13]. Falls are simulated according to the scenarios defined by Noury et al. [14] and by adding additional scenarios defined by Planinc and Kampel [13]. These scenarios are simulated by two subjects, simulating each scenario twice. This results in an overall set of 72 videos, containing 40 falls and 32 no-falls. The approach used in the *fearless* system yielded an accuracy of 98.6 % on 72 videos, resulting in one FP in the whole dataset. This FP occurs due to a tracking error after a fall, since the person is not tracked correctly while getting up again. Hence, a second

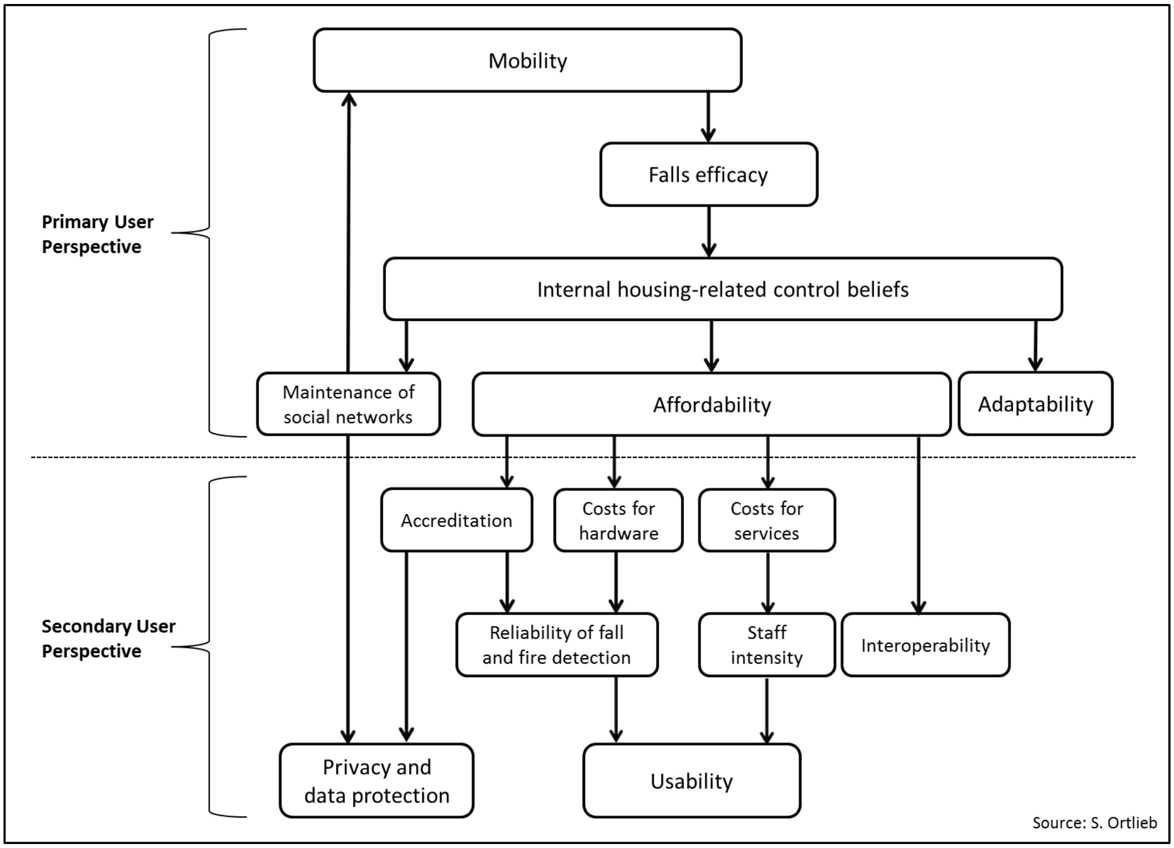

Figure 8. Technological Impact Assessment Model (TIAMo) describing the interdependencies of user requirements

fall is detected within the same sequence but as this fall does not occur in the time interval specified in the ground truth annotation, it is marked as a FP. Furthermore, the use of the Kinect™ offers practical advantages: it is robust to changing lighting conditions, also works also during the night and the installation in real homes is simplified by using only one sensor without the need for a complex calibration.

Staff intensity. Especially for care taker organizations from Germany it is difficult to recruit qualified care personnel. Also for the sake of labor costs operating the *fearless* system should be less labor intensive than a conventional tele-care systems (e.g., panic button). How do we assess staff intensity? The "Expert Checklist" contains three items targeting staff intensity ("Compared with the tele-care devices we have been using so far the *fearless* system is very efficient in terms of staff intensity."), maintenance ("Compared with the tele-care devices we have been using so far the *fearless* system needs very little maintenance.") and training effort ("Compared with the tele-care devices we have been using so far the *fearless* system can be operated without intensive training.") related to the *fearless* system. Each of these items features a five point rating scale ranging from 1 = "I strongly disagree" to 5 = "I strongly agree".

Accreditation means that the *fearless* system is officially certified and listed as an assistive device. As accreditation is a major precondition for reimbursement it contributes to the affordability of the projected e-health system. What are appropriate criteria for accreditation? National as well as European criteria for certification are applied to the *fearless* system.

Affordability / Costs for hardware and services. The projected e-health system and the services related to it should be affordable even for elderly people with limited financial resources. What are appropriate criteria for affordability? According to our survey data the hardware should be less than 200 Euros and monthly expenses for services related to it should not exceed 50 Euros.

Interoperability means that hardware and software of the e-health system should be compatible with the given IT-environment of care taker organizations. An e-health system that is interoperable with an existing infrastructure contributes to affordability as it does not require subsequent investments. How do we assess interoperability? Interoperability of the *fearless* system is operationalized by one item of the "Expert Checklist": "In general the *fearless* system is compatible with existing hardware and software and provides all necessary interfaces". Employees of care taker organizations who have worked with the *fearless* system during pilot implementation phase are asked to rate their approval of this statement on a five point rating scale ranging from 1 = "I strongly disagree" to 5 = "I strongly agree".

B. Measures and Criteria for the Primary User Perspective

The TIAMo characterizes the primary user perspective by a set of five requirements (Figure 8): (9) housing-related control beliefs, (10) fear of falling/falls efficacy (older persons confidence in performing everyday tasks without falling) (11) mobility and (12) maintenance of social networks, illustrated in Figure 10. In addition, overall housing satisfaction is assessed. The requirement "affordability" is covered by "costs for hardware" and "costs for services" in the secondary user perspective.

Housing-related control beliefs. People who state a strong internal housing-related control belief are convinced that they are in control of their private home environment [15]. By contrast people with external control beliefs feel that their life is either controlled by powerful others (e.g., "I rely to a great extent upon the advice of others when it comes to helpful improvements to my apartment / house" [15]) or by mere chance (e.g., "Having a nice place is all luck. You cannot influence it; you just have to accept it" [15]). Older people displaying a high level of externality are prone to feelings of helplessness and depression. Therefore, reducing external control beliefs and/or sustaining an internal housing-related control belief must be considered as prerequisites for fear resolution and psychological well-being. How do we assess housing-related control beliefs? In order to capture housing-related control beliefs 16 items from the Housing-related Control Beliefs Questionnaire (HCQ) by Oswald et al. [15]) were included into our feedback questionnaire. The HCQ is a 24-item questionnaire "based on the widely used psychological dimensions of Internal Control (8 items, sum-score), External Control: Powerful Others (8 items, sum-score), and External Control: Chance (8 items, sum-score)" [16, p. 192]. Participants are instructed to rate their approval of certain statements (e.g., "Having a nice place is all luck. You cannot influence it; you just have to accept it" [15]) on a five-point rating scale ranging from 1 = "not at all" to 5 = "very much". Due to the poor psychometrical quality of the internal control scale only the two external control subscales (8 items + 8 items) of the HCQ were included into our feedback questionnaire.

Fear of falling refers to the worries of an older person in terms of falling in his/her home. Fear of falling has serious consequences for older people [17]. Elderly who are very worried about falling tend to limit their physical activities in order to reduce their risk of falling. Since fear resolution is the main objective of the *fearless* system this variable will be examined closely during pilot implementation. For the measurement of fear of falling we prefer the construct falls efficacy. Falls efficacy is defined as an "older persons confidence in performing a series of everyday tasks without falling" [18, p. 299]. How do we assess fear of falling/falls efficacy? According to Tinetti et al. [18] the Falls Efficacy Scale (FES) can be considered as a valid estimate for fear of falling. Thus, our feedback questionnaire includes the complete Falls Efficacy Scale (FES) by Tinetti et al. [18]. The FES consists of 16 Items describing activities that may be challenging for elderly (e.g., "Reaching for something above your head or on the ground"). For each activity participants are asked to rate their concerns in terms of falling in the course of this particular activities on a five point rating scale ranging from 1 = "not at all concerned" to 5 = "very concerned".

Mobility refers to the test users level of physical activity in terms of locomotion. By enhancing falls efficacy we expect the fearless system to disinhibit mobility among our test users. Ideally, this effect is not limited to the range of the ambient event detector. Thus, for mobility assessment we have combined indicators for indoor as well as outdoor activities (e.g. grocery shopping). Enhancing mobility is an important objective of the *fearless* system since it is a prerequisite for social participation.

Social participation refers to the frequency of test users social activities and the number of different people involved in these activities. Social bonds are a powerful source of self-confidence. Installing an automated event detector in the private home of an elderly person may affect social activities. The impact of the *fearless* system on social activities has to be examined throughout the pilot phase.

How do we assess mobility and social participation? The Nordic mobility-related participation outcome evaluation of assistive device intervention (NOMO) by Brandt et al. [19] allows for a combined assessment of mobility and social participation: 21 items of the NOMO capturing the "frequency of mobility-related participation and ease/difficulty in mobility during participation" [19, p. 18] have been included into the feedback questionnaire. Each item describes a certain activity of daily living, which requires physical activity (e.g., washing clothes or garments). The participants are instructed to estimate how frequently they conduct this activity (e.g., "How often do you do grocery shopping?"). For our feedback questionnaire these questions have been slightly modified: Participants are asked to estimate how frequently they have conducted certain activities in the course of the last month (e.g., "In the last month how often did you do grocery shopping?"). Moreover, the multiple choice format of the NOMO has been replaced by a cloze ("About x times."). The feedback questionnaire reflects the test users personal view in terms of mobility. For outcome assessment this self-report data is very valuable, yet it may be biased (e.g., by selective memory processes). Thus, every test user will be equipped with a portable step counter device in order to collect more objective data on his/her level of physical activity.

Housing satisfaction describes the overall "satisfaction

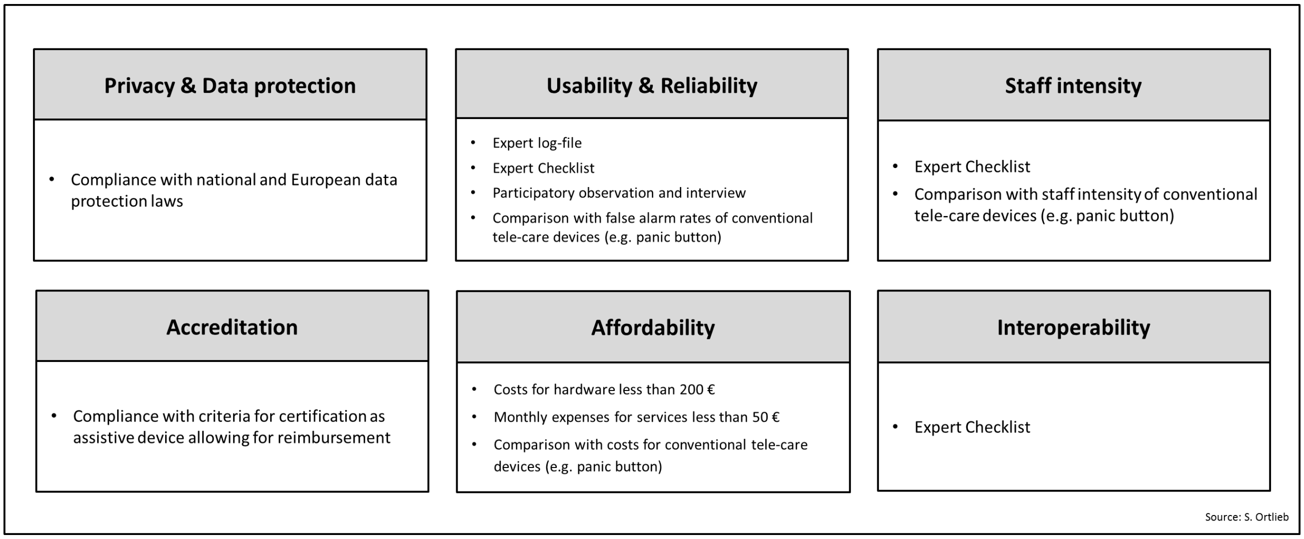

Figure 9. Overview of measures and indicators based on data from the secondary user perspective

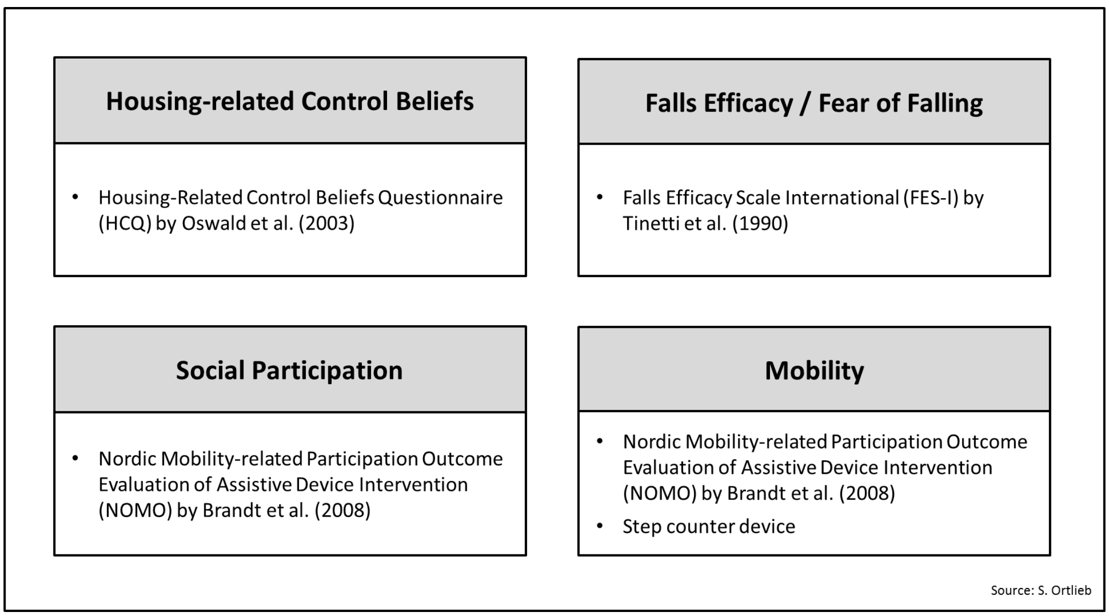

Figure 10. Overview of measures and indicators based on data from the primary user perspective

with the condition of the house“ [16, p. 192]. Introducing a novel assistive technology such as the *fearless* system to the homes of our test users is likely to affect their housing satisfaction. In our feedback questionnaire housing satisfaction is captured by a single item measure (“Are you happy with the condition in your home?”). This item was taken from the more extensive Housing Options for Older People (HOOP) by Heywood et al. [20]. It is answered on a five point rating scale ranging from 1 = “definitely not” to 5 = “yes, definitely”.

VIII. Challenges in the User-Centered Design Process

Which aspects have to be balanced in the user-centered design process? At first glance, the requirements described in the TIAMo seem perfectly compatible. Yet a closer look reveals at least four goal conflicts that have to be addressed and balanced in the process of system development and evaluation: (1) affordability versus technical performance, (2) need for control versus automation, (3) security versus privacy, (4) social needs versus personnel intensity. These four trade-offs are described and design recommendations are discussed in the following sections.

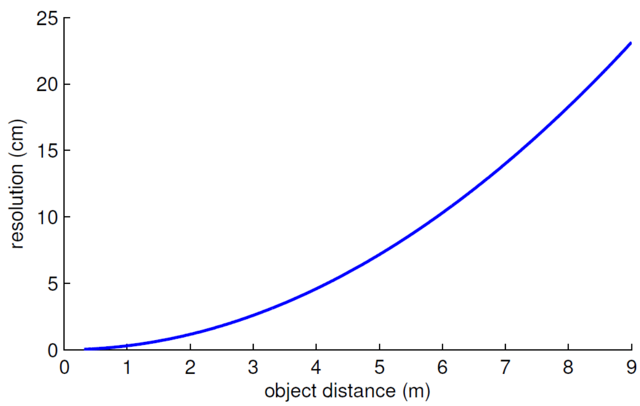

Figure 11. Resolution of the Kinect™ sensor depending on the distance [21]

A. *Affordability versus Technical Performance*

Research in the field of depth-sensor technology is very dynamic. Depth-sensors are relentlessly being improved in terms of accuracy and range. Although cutting-edge technology excels todays off-the-shelf sensors it is still comparatively expensive. Thus, a trade-off between technical performance and affordability has to be found. Since the Kinect™ sensor was introduced by Microsoft in 2010, a cheap depth sensor (in comparison to other depth sensors) is available. An evaluation of the depth sensor by Pramerdorfer [21] showed the feasibility of the Kinect™ sensor for fall detection. The precision of the sensor is analyzed depending on different distances, lighting conditions and surfaces. The accuracy of the sensor is reduced at higher distances but results in resolution being high enough to detect falls properly. Figure 11 shows the dependency of the accuracy (here resolution per pixel) and the distance: at a distance of one meter, the resolution is less than one centimeter. Whereas at a distance of nine meters, the resolution is above 20 cm per pixel, resulting in a reduced accuracy. However, in comparison to more accurate but more expensive devices (e.g., Pmd CamCube, Fotonic P70, Argos 3D) the accuracy of the Kinect™ is sufficient to detect falls reliably.

The Kinect™ uses structured light to obtain depth information from a scene. This results in the drawback, that the Kinect™ can only be used indoors since direct sunlight interferes with the structured light and thus no depth information can be obtained. This trade-off was made in the *fearless* project due to the goal of providing an affordable system. However, the new version of the Kinect™ presented in 2013 already uses time of flight for obtaining depth information and thus will be more stable to different lightening conditions (especially including direct sunlight).

B. *Need for Control versus Automation*

In 2008, guideless underground trains were introduced to the public transportation system of the city of Nuremberg, Germany [22]. Many senior citizens opposed to these plans. They felt uncomfortable being at the mercy of an autonomously operating transportation system and signalized that in the future they would choose other means of transportation where conductors of "flesh and blood" are available in case of an emergency. This example illustrates a second challenge we are facing in the user-centered development process of an automatically operating event detector: primary users need for control versus the benefits of automated fall detection. Internal control beliefs are defined as a strong confidence in ones abilities to control ones own life. On the contrary, people displaying external control beliefs feel that their life is controlled either by environmental factors (e.g., powerful others) or by mere chance. A strong notion of internal control is essential for psychological well-being in general and fear resolution in particular [23]. To a certain extent control beliefs vary across different life domains. Housing-related control beliefs refer to a persons private home: elderly people stating strong internal housing-related control beliefs are convinced that they can exert control over their private home environment. By contrast, people with external control beliefs feel that their life is either controlled by powerful others or by mere chance. Older people displaying a high level of externality are prone to feelings of helplessness and depression [24].

How does this relate to the *fearless* system? From a technical point of view reliability and accuracy of fall detection and inactivity monitoring can be improved by automation. A conventional panic button for example is useless if the client passes out or forgets to wear it. Yet from a psychological point of view, automation always implies giving away control to a technical device. In case of a panic button an alarm is actively released by the client himself/herself. Thus, introducing an autonomously operating ambient event detector to the private home of an elderly person must not undermine his/her internal housing-related control beliefs. How can we compensate this loss of control due to automation? First of all, we recommend a user interface, which provides immediate feedback and allows for active control of the ambient detector. Immediate feedback means that there is a user interface, which gives answers to the following questions: What is the current status of the system? Is it working properly? Does it require maintenance? Has an alarm been released? Active control means that the system can be switched on and off, that alarms can also be released manually and that false positives can be cancelled by the user.

From a technical point of view, these requirements can be integrated in the system easily: LEDs can symbolize the current status of the system (e.g., light blue = system active, red = alarm triggered, no light = system off) and an easy accessible on/off switch maintains the control beliefs of elderly since they are able to switch the system off at any time. Furthermore, the system can be combined with the already established contact devices already used in combination with the panic button: in case of a triggered alarm, voice communication to a call center, care taker organization or relative can be established and thus the *fearless* system is an additional device enhancing the safety of elderly in their homes.

C. Security versus Privacy

In case of an alarm the *fearless* system generates a visualization of the scene at the clients home. This visualization is sent to the care taker organization for alarm verification. Based on these visualizations, employees of the care taker organization have to discriminate between, e.g., a fall and a false alarm. The quality of these visualizations gives rise to a third goal conflict: fast and correct alarm verification requires very detailed images, whereas for the sake of privacy protection a low level of resolution is desirable (see [25], [26]).

How can we solve this goal conflict? For instance, alarm verification via depth-images could be replaced by direct voice contact in case of an alarm. Many care taker organizations already use direct voice contact in combination with a panic button device: in case of an alarm the client receives a verification call from the call-center of the care taker organization. If the client answers this call, his/her need for assistance can be specified. If not, further measures are taken (e.g., an ambulance is sent to the clients home). If this well-tried routine was combined with the *fearless* sensors the dilemma between security and privacy could be resolved. Allowing for direct voice contact between clients and care taker staff brings us to the next crucial trade-off between the clients need for communication and personnel intensity on the service providers side. However, this solution only applies to the final system. During the technical development within the *fearless* project and the pilot phases A and B, another trade-off needs to be found. The verification image is needed not only for care taker staff to decide whether a fall has occurred or not, but also for technical staff developing the system and thus not only information if a false alarm has occurred but also why this false alarm has occurred need to be gathered. Hence, different visualizations are developed as shown in Figure 12. Most information is included in RGB images, allowing to verify if a fall occurred and identifying the problem of false alarms easily. However, due to the lack of privacy protection, no RGB images are transmitted at any time. Depth images are used during the pilot phase in order to verify if a fall occurred and the system is working properly. These images were found to be a trade-off during the pilot phases were the system is still under development but the privacy aspects need to be considered. However, if the technical system is working properly, more abstract visualizations (e.g., top-view and 3 dots representing the upper body with respect to the ground floor) can be applied in order to allow the verification of false alarms by care takers. Evaluation showed that the visualization containing only the ground floor, three dots and a line is even more helpful than a top view image showing the shape of a person lying on the floor since it can be interpreted more easily. Nevertheless, a direct voice communication is seen as the best way to verify if a fall has occurred while respecting the privacy of elderly.

D. Social Needs versus Personnel Intensity

In the field of AAL a strong emphasis is usually put on self-determination and independence of elderly people. Yet social relatedness and the feeling of belonging to a valued group (e.g., family, neighborhood, religious community, etc.) are equally important for our psychological well-being as humans. Moreover, our needs for autonomy and affiliation are dynamically interrelated and cannot be treated as separate entities [27]. For instance, the ability to interact and communicate with members of a valued group adds to an elderly persons notion of competence. As an elderly persons level of functioning is gradually decreasing, social bonds play an increasingly important role in stabilizing control beliefs. Thus, the relevance of affiliation for the resolution of elderlies fears has to be taken into account.

In our primary user requirement survey we have found that social isolation is a problem particularly for solitarily living elderly from Austria and Germany [12]. In addition, our secondary user requirement survey shows that many false positive alarms that are raised by client's wearing a panic button actually reflect their need for affiliation: they press the button because they are longing for someone to speak to. As a consequence some care taker organizations do not consider these events as false positives but as a different kind of alarm, which requires as much attention as for example a severe fall. For these organizations providing social support is part of their mission. On the other hand, dealing with these "false positives" is staff intensive. In our secondary user requirement analysis the issue of staff intensity was often raised by representatives of care taker organizations from Germany. Since mandatory civil service has been abolished in Germany trained care personnel is scarce and labor costs are increasing.

How does this relate to the *fearless* system? In case of a fall the *fearless* system releases an alarm automatically. Verification images of the scene can be used for alarm verification by members of the care taker organization. Thus, no social interaction (e.g., via direct voice contact) takes place between clients and care taker personnel. For the staff of care taker organizations this may be beneficial in terms of staff intensity. For primary users this procedure is likely to yield acceptance issues: as in the case of the guideless underground trains elderly users might prefer a care taker of "flesh and blood" to an efficient yet anonymous e-health system. This results in the fact, that the *fearless* system may server as additional system for fall detection, when

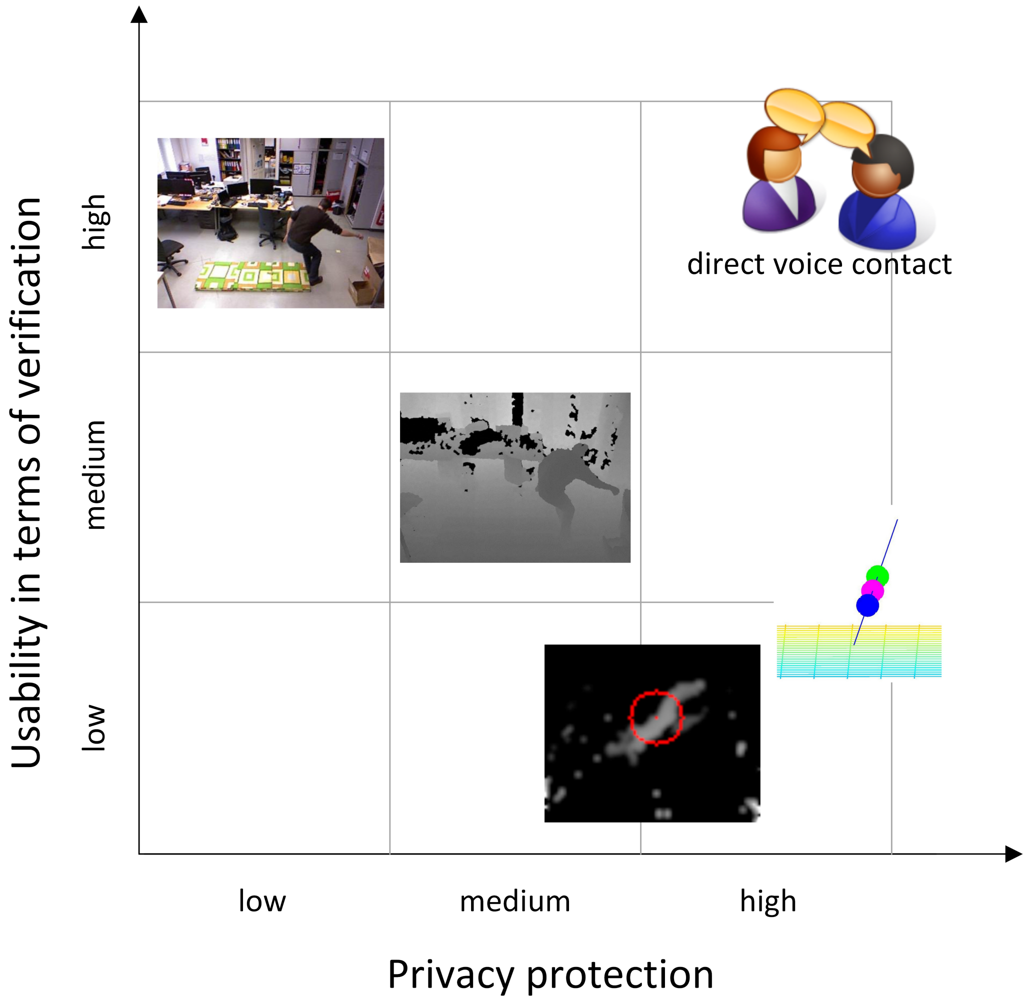

Figure 12. Usability versus privacy protection

a client is not able to push the button but not replacing an already established panic button system. However, this increases staff intensity on the care taker's side. Thus, yet another trade-off has to be found.

IX. Conclusion

In this paper, we have outlined a performance measurement system that has been tailored to the specific challenges of the AAL-JP project *fearless*. Based on the Technological Impact Assessment Model (TIAMo) its measures reflect two different user perspectives: older adults as primary users and care taker organizations as secondary users. Moreover, it describes the interplay of technical, psychological and business aspects related to the projected e-health system. By creating a common understanding of different user perspectives among our multi-disciplinary project partners this balanced scorecard will guide our actions in the next stages of the user-centered design process. What are the next steps to be taken? A pilot study is planned during which the *fearless* system will be installed in the private homes of 45 test users from Austria, Germany, Italy, and Spain. This pilot study lasts four months including pre-test and follow-up test, during which test users and care taker personnel will be contacted on a regular basis to assess the measures described in the *fearless* scorecard.

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